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Fuzzy Logic Hysteresis Control of A Single-Phase on-Grid Inverter: Computer Investigation

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ABSTRACT

This paper presents a realization of fuzzy-logic hysteresis control of a single-phase on-grid inverter. The inverter used for the research is implemented by the full-bridge power circuit and it is connected to the utility grid by means of LCL filter. For the purpose of the computer simulation the relative mathematical equations are issued. The research of the model established by these equations is done by means of computer simulation with the software MATLAB/SIMULINK. The operation of the model combines two non-linear control methods - fuzzy control and hysteresis control. Simulation results and their analysis are included. The operation of the model of the inverter is analyzed in two different cases of the output power of the system - 800W and 1600W approximately.

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1. INTRODUCTION

Control of on-grid inverters is mainly based on the two most used engineering methods of current control - the Pulse Width Modulation (PWM) and the hysteresis control including their advantages and disadvantages [1], [2]. In the recent years, with the growing demand for use of renewable energy sources for the generation of green energy, researches have been done in order to improve the control of the on-grid inverter and make it more efficient. Fuzzy logic control was combined with regular hysteresis control [3], [3]. Fuzzy logic control theory is mathematic concept which allows the solution of not very precise problems and it is based on incertitude and vagueness [5]. [6] describes the operation of on-grid interactive inverter operating by means of fuzzy logic as well as basic rules of the fuzzy theory. Inspiration for the concept of the fuzzy logic hysteresis control of grid inverters can be found in similar type of control for the active power filters [7], [8]. The principle is the same - combination of hysteresis and fuzzy controls.

The other type of control used in this paper - the hysteresis control is based on creation of reference signal which is compared constantly with the output signal of the inverter which should be controlled. The hysteresis control can be constant or adaptive [8]. The hysteresis control is also used for active power filters [8] and for on-grid inverters [9]. One of the major advantages of this method is its easy implementation and very good performance on the other hand its major disadvantage is the high switching frequency.

In this paper, MATLAB/SIMULINK environment is used to simulate fuzzy-logic hysteresis-controlled single-phase on-grid inverter, connected to the grid via LCL filter. The implemented control is combination of fuzzy logic and hysteresis control. Three different values of hysteresis are used according to the current value of the difference between the transitory values of the current of the inverter and the reference current. The authors' aim is to show the efficiency of the combination of the two control methods for the operation of the model.

This paper is organized as follows: Section II describes the fuzzy logic hysteresis controlled single phase grid inverter. Section III presents the simulation results. Section IV is the conclusion.

2. RESEARCH METHOD

The inverter is fed by photovoltaic system. The voltage U_{PV} of the photovoltaic modules is obtained by means of boost DC/DC converter. The converter stabilizes the value of the voltage U_{PV} and also keeps it constant. The block diagram of the system including the inverter, filter and the grid is shown in Figure 1. The following equations are derived:

$$i_{L_1} = \frac{v_{PV} - v_C}{s * L_1}; \quad i_{L_2} = \frac{v_C - v_{PCC}}{s * L_2}; \quad i_{source} = \frac{v_{PCC} - v_{source}}{s * L_s + R_s};$$
$$v_{PCC} = i_{load} * R_{load},$$

where in s is the Laplace's operator and all others variables are shown in the figure.

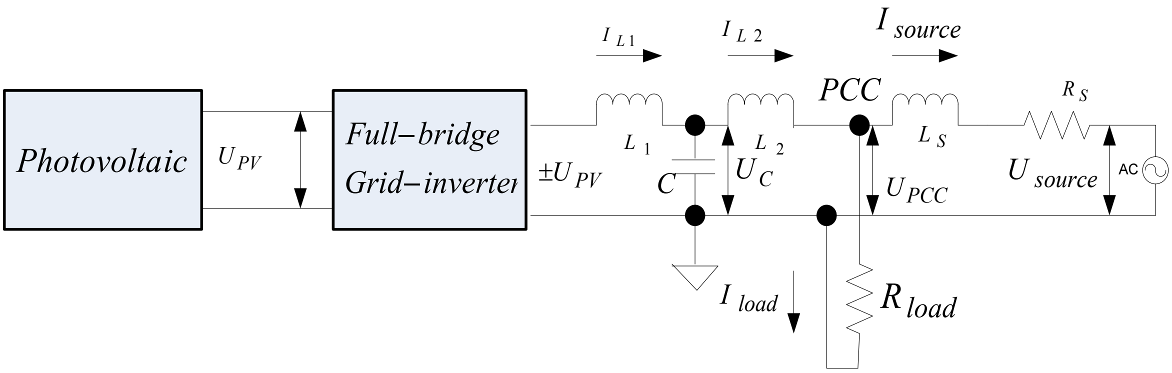

Figure 1. Block diagram of the system

Standard fuzzy logic controller is using membership functions to define the input variable or variables as well as the output variable. They can be of different type but the most frequently used is the triangular membership function as the ones presented in Figure 2. The linguistic input variables are used according to different rules which can be synthesized in the Table1 and it also defines the states of the output variable. The definitions of the values of the variables corresponding to the linguistic variables are usually defined by the experience of the person programming the fuzzy controller.

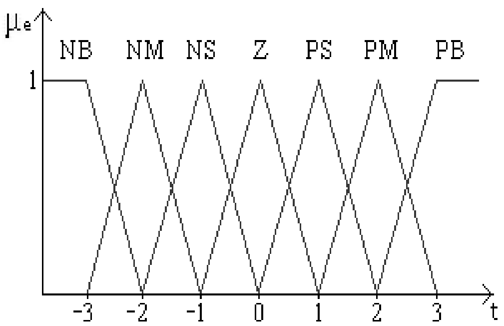

Figure 2. Membership functions - general view

Table 1. Linguistic variables combinations

ce\ e	NB	NM	NS	Z	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	Z
NM	NB	NB	NB	NM	NS	Z	PS
NS	NB	NB	NM	NS	Z	PS	PM
Z	NB	NM	NS	Z	PS	PM	PB
PS	NM	NS	Z	PS	PM	PB	PB
PM	NS	Z	PS	PM	PB	PB	PB
PB	Z	PS	PM	PB	PB	PB	PB

In this paper the fuzzy logic is implemented not by the Fuzzy Logic Controller block of MATLAB/SIMULINK Fuzzy Logic Toolbox but by means of conditional equations based on the fuzzy logic. The idea is according to the comparison of the transitory values of the inverter output current and the reference current to produce output signal based on fuzzy logic by choosing one of the three set values of the hysteresis and depending on this choice to produce the output signal equal to 1 or (-1). The fuzzy-logic based equations are described here below:

```
if (iL1≥H1| iL1≥H2| iL1≥H3 ) {
        -1;
        }
else if (iL1≤H1| iL1≤H2| iL1≤H3){
        1;
        }
```

3. RESULTS AND ANALYSIS

The simulation was performed in MATLAB/SIMULINK environment. Figure 3 presents the simulation model. The system parameters are the following:

$H_1 = 0.1\ A$; $H_2 = 0.25\ A$; $H_3 = 0.5\ A$; $I_{ref} = 5\ A$; $V_{pv} = 400V$; $L_1 = 2.5\ mH$; $C = 2\ \mu F$; $L_2 = 40\ \mu H$; $V_s = 335\ V$; $L_{source} = 127\ \mu H$; $R_{source} = 12.3\ m\Omega$;

For the needs of the software currents, voltages and hysteresis values are lessened by the factor of 100, in order to be operated in the range of the variables of MATLAB/SIMULINK.

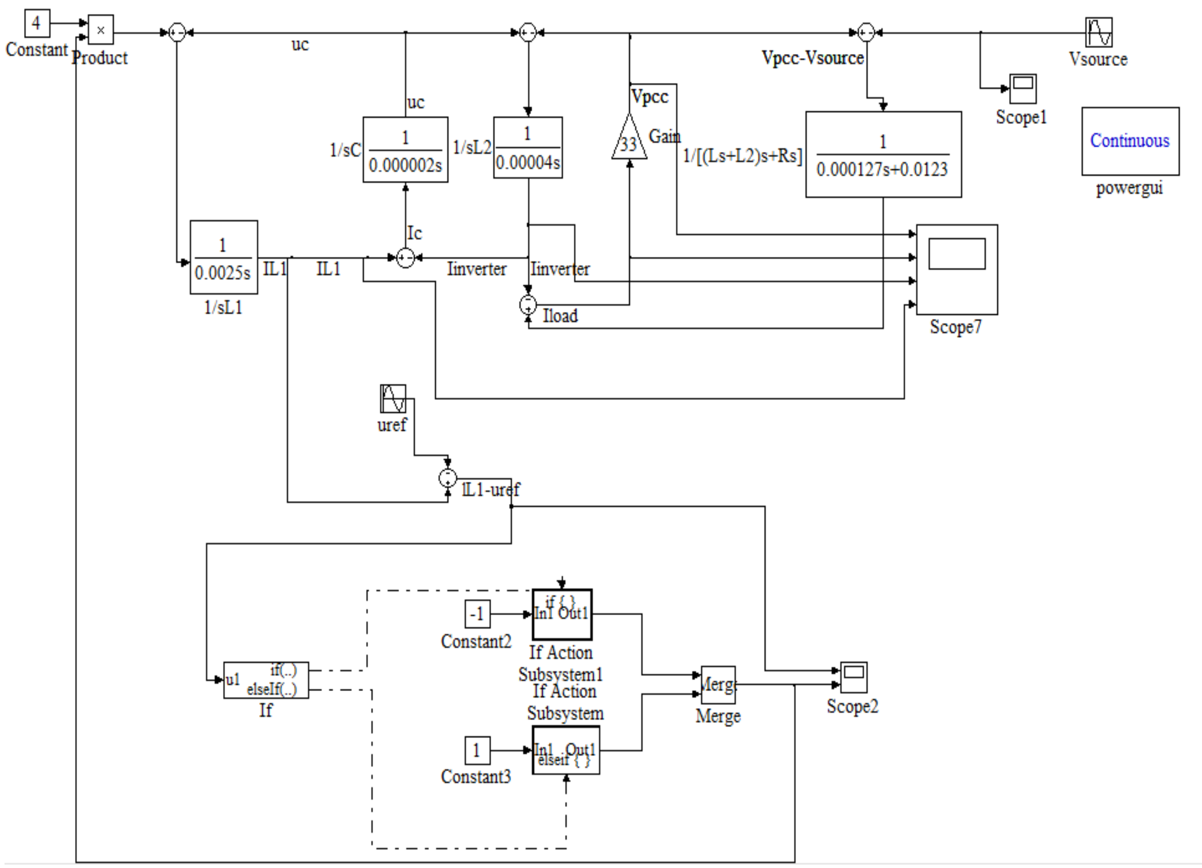

Figure 3. Simulation model of fuzzy-logic hysteresis control of single-phase grid inverter

Simulation analysis is done in two cases - $R_{load} = 68\Omega$ and $R_{load} = 33\Omega$. For both cases are presented waveforms in the time domain for the following variables: V_{PCC} , I_{source} , I_{L_2} , I_{load} as well as frequency domain analysis for V_{PCC}, I_{source} in two different coordinate systems - from 0 to 2kHz and from 2kHz to 100kHz. These results are presented in Figure 4 ($R_{load} = 68\Omega$) and in Figure 5 ($R_{load} = 33\Omega$).

3.1. $R_{load} = 68\Omega$ Corresponding to the Output Power of the System Approximately 800W

From the results of the simulation for the first case ($R_{load} = 68\Omega$) presented in Figure 4 a) which refers to the time domain, one can observe the following waveforms: the voltage in the point of common coupling (V_{PCC}), the load current (I_{load}) which is in phase with V_{PCC}; the inverter current (I_{L1}) which has the same maximum value as the load current and it is displaced in 180degrees to V_{PCC}; and the grid current I_{source} which has a very small maximum value and it is not in phase with the (V_{PCC}). Harmonics spectrum analyses are presented in Figure 4 b), c).

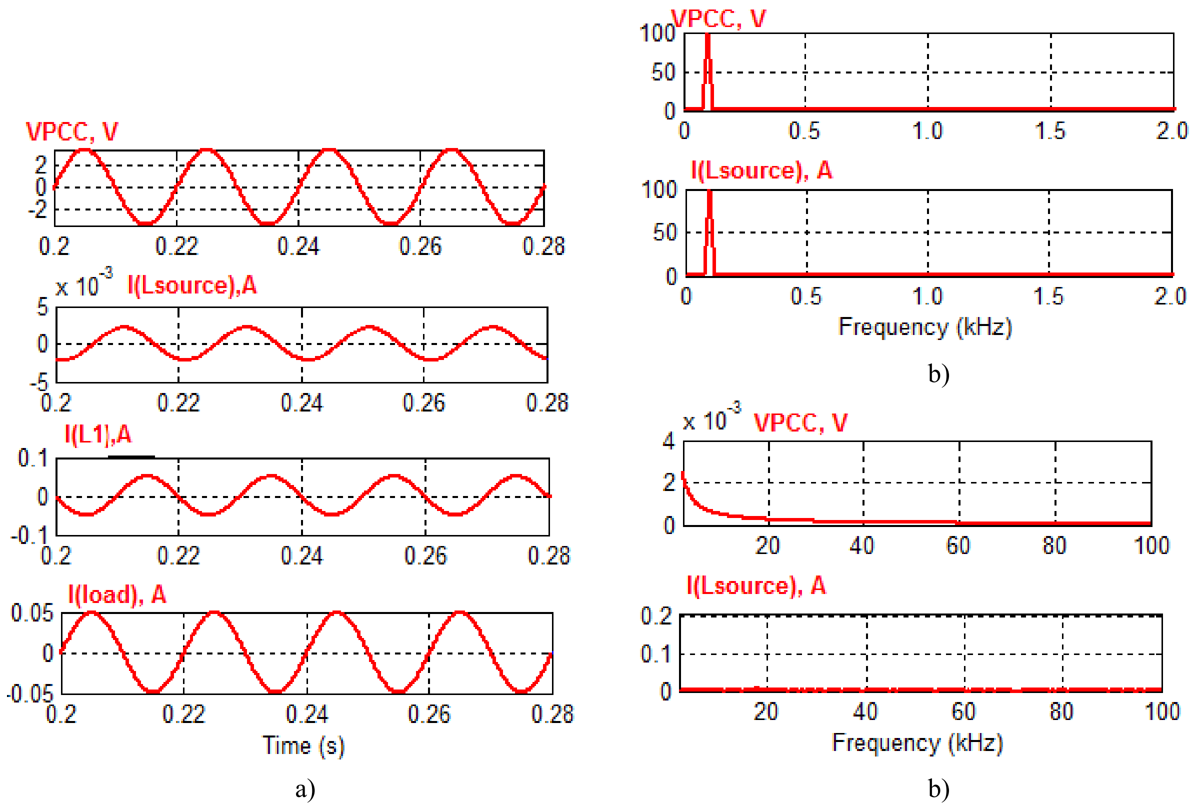

Figure 4. Simulation results when the load is $R_{load} = 68\,\Omega$. a) time domain from top to bottom: voltage of the PCC, grid current, inverter current, and load current; b) harmonic spectrum analysis of the voltage of the PCC and source current from 0 to 2 kHz; c) harmonic spectrum analysis voltage of the PCC and source current from 2 to 100kHz

3.2. $R_{load} = 33\Omega$ Corresponding to the Output Power of the System Approximately 1600W

From the results of the simulation for the second case ($R_{load} = 33\Omega$), presented in Figure 5a) which refers to the time domain, one can observe the following waveforms: the voltage in the point of common coupling (V_{PCC}); the load current (I_{load}) which is in phase with V_{PCC}; the inverter current (I_{L1}) displaced in 180degrees to V_{PCC}; the grid current I_{source} is in phase with the V_{PCC}. The grid supplies the half of the active power required by the load. Harmonics spectrum analyses are presented in Figure 5 b), c).

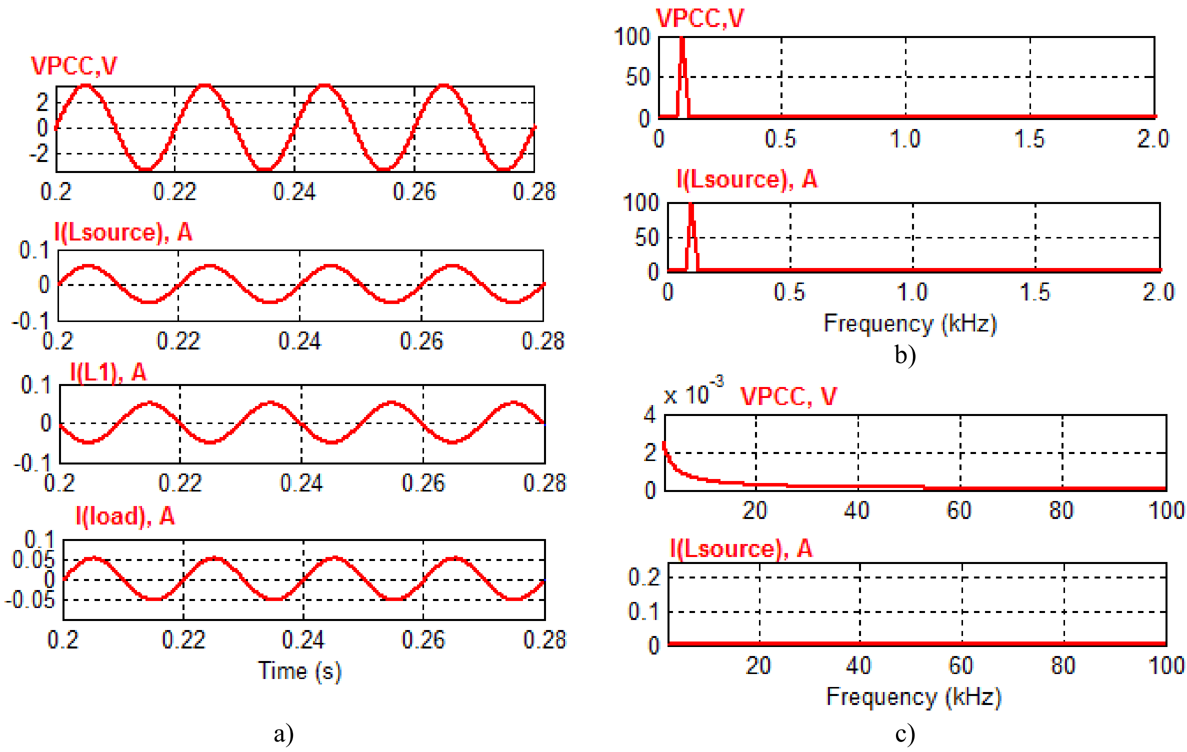

Figure 5. Simulation results when the load is $R_{load} = 3\Omega$. a) time domain from top to bottom: voltage of the PCC, grid current, inverter current, and load current; b) harmonic spectrum analysis of the voltage of the PCC and source current from 0 to 2kHz; c) harmonic spectrum analysis voltage of the PCC and source current from 2 to 100kHz

4. CONCLUSION

The proposed method shows very good results for the control of a grid inverter. From the simulation results for the harmonic spectrum analysis, we can conclude that with this type of control the inverter will not inject any distortion in the public grid. The waveforms for the current injected are also in conformity with the standards, which prove the suitability of this control for grid connection of inverters.

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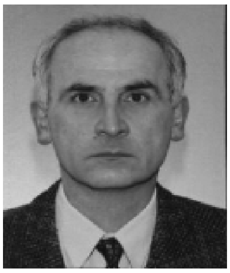

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